INNOVATIVE BALLOON BUOYANCY TECHNIQUES FOR ATMOSPHERIC EXPLORATION

Jack A. Jones

ABSTRACT

Until quite recently, the only practical means to control balloon buoyancy, and thus altitude, required consuming large amounts of fuel or the limited venting of helium balloons and/or dropping of ballast. With recent discoveries at JPL, **novel long-life, balloon buoyancy techniques have been discovered that for the first time allow balloons to float in the primarily hydrogen atmospheres of Jupiter, Saturn, Uranus, and Neptune (using ambient fill-gas), and by using renewable energy sources, allow *multiple controlled landings* on Venus (using atmospheric temperature differences), Mars (solar heat), Titan (RTG heat), and Earth (planet radiant heat)**. A test program has been initiated at JPL to confirm these basic new buoyancy principles. The Earth balloon work will be performed in conjunction with GSFC to apply these techniques to increase controllability of scientific terrestrial balloons. **These novel techniques may enable many exciting, yet *economical and practical* scientific balloon missions to seven planets and one moon in our own solar system, and in fact, may eventually be the basis for in situ exploration of planets in *other* solar systems.**

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BACKGROUND

There are five basic balloon concepts that have been flown numerous times in the Earth's atmosphere. The simplest concept is known as a zero-pressure helium balloon and consists of a balloon partially filled with gas. This balloon is, at best, metastable at any altitude and will eventually go up or down depending on the amount of helium in the balloon. Multi-day floatations with this balloon type are possible only with venting of helium during the day and/or dropping of ballast at night.

Another type of helium balloon is known as a super-pressure helium balloon, and it has an internal pressure slightly higher than ambient. It floats at an altitude where the ambient gas it displaces is equal to the entire mass of the balloon system. It will have a higher pressure during the day than at night, and floats at a nearly constant altitude.

Another common type of commercial balloon is a hot air balloon, wherein ambient air is burned with propane, and the hot exhaust gas creates buoyancy. A variation of this is a solar-heated balloon, wherein a solar-absorptive black balloon creates buoyancy by heating the contained ambient air. Both of these hot air balloons are also called Montgolfieres, named after the 18th century Montgolfier brothers who flew the world's first hot air balloon.

A fifth type of balloon is known as an infrared Montgolfiere, and flies in the Earth's cold stratosphere by heating from the sun during the day and by trapping lower Earth planetary radiation at night. The French have flown over forty such balloons[7] since the 1970's, the longest of which lasted 69 days and encircled the Earth twice. These balloons generally have a fixed daytime altitude and a fixed nighttime altitude.

The balloon buoyancy control concepts described in following sections use various aspects of these five basic balloon concepts with a number of recently discovered balloon buoyancy techniques to allow controlled balloon flights in the atmospheres of seven planets and one moon in our solar system.

NEW BASIC BALLOON BUOYANCY PRINCIPLES

There are four newly discovered, basic principles that will allow buoyancy controlled balloons on all the atmosphered bodies in our solar system. These principles are:

- **Phase change fluids** will condense in the upper atmosphere of a planet, and boil in the lower atmosphere, such that the balloon bobs about an equilibrium altitude[1]. We have demonstrated this principle on Earth using a variety of fluids[2], and researchers have proposed using water at Venus[3] to bob at about 42 km above the surface (130 °C, 2.7 bar). JPL has recently discovered that by adding helium (a non-condensable fluid), to the water, the condensation can be inhibited and buoyancy improved, while moving the peak condensation altitude considerably higher[4], e.g. to 62 km (-20 °C, 0.16 bar). This benefit will now allow intermittent cooling of instruments. Furthermore, by trapping the condensed water in an insulated container before it boils, controlled landings can occur, with re-ascent caused when the water is again boiled (Figure 1).

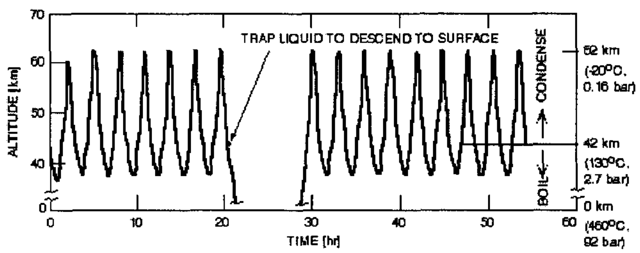


Figure 1. Venus Mixed Fluid Balloon Altitudes

- **Solar-heated hot air balloons**, or solar Montgolfieres, can provide buoyancy for balloons at any planet near the sun[5] (<10 AU). Tests on Earth, have in fact, confirmed this simple principle[6]. With a recent novel, JPL-developed, radio-controlled, upper hot air vent, the balloon buoyancy can now be to provide precise altitude changes and can actually provide controlled landings at Mars (Figure 2) and altitude controllability at Venus, Jupiter, and Saturn[6]. Solar-heated, hot air balloons are the only viable means to fly balloons at the primarily hydrogen planets of Jupiter and Saturn. Infrared Montgolfieres[7] are balloons that are heated by lower radiant Earth heat (low radiation emissivity to space), thus maintaining buoyancy. When an upper vent is used in combination with a more weight-efficient, zero-pressure helium balloon to provide buoyancy during the day, this system can create a lightweight, simple means to provide controlled altitude on Earth, including increased altitude at night[8] (Figure 3) and the ability to land controllably.

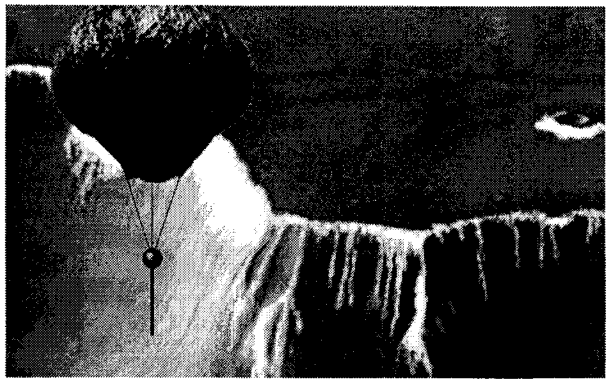
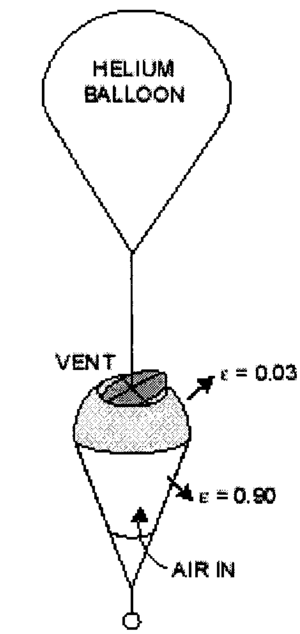


Figure 2. Mars Solar Montgolfiere

Figure 3. Helium Balloon with IR Montgolfiere



- **Filling a balloon with light, methane-free, stratospheric gas** is a technique that can be uniquely used at Uranus and Neptune to provide buoyancy in and below the cold methane clouds[9] (Figure 4) This newly-discovered buoyancy technique is presently the only viable means to float balloons at these planets.

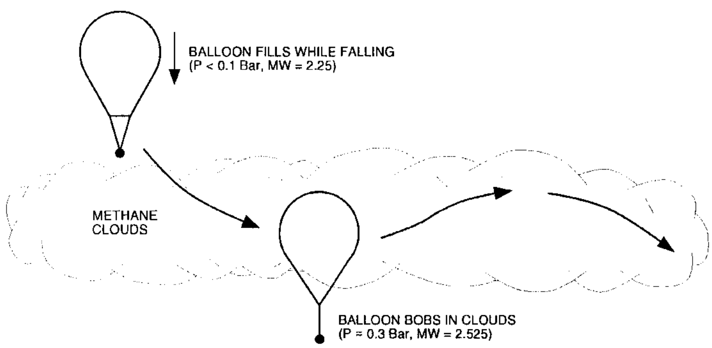


Figure 4. Trapped Light Gas Balloon at Uranus/Neptune

- **RadioactiveThermal Generator (RTG) waste heat can control a balloon's buoyancy** by directing the heat in and out of the helium balloons. This technique works very well at Titan[10](Figure 5), which is far from the sun, and is cloud-enshrouded, thus, prohibiting the use of the sun for power or buoyancy. This method also helps ensure that atmospheric methane does not freeze on the balloon.

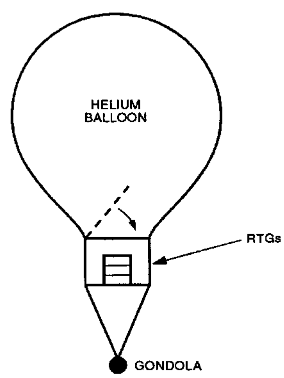


Figure 5. Titan Balloon Altitude Control

APPLICATION OF NEW BUOYANCY PRINCIPLES

- **Phase change water balloons** have been previously proposed for buoyancy control of Venus balloons[3], and JPL has flown many Earth simulations of this type of phase-change balloon buoyancy technique[2]. Through the JPL flights, which used R114, it was discovered that it is relatively easy to control the altitude below the equilibrium point, simply by preventing or inhibiting boiling. Above the equilibrium point, however, it was almost impossible to physically prevent condensation in the large surface area balloon. Recent JPL analysis has shown, however, that the addition of helium can significantly inhibit condensation while increasing buoyancy, and thus allow the balloon to reach higher cooling altitudes[4]. Tests are presently planned to confirm this technique ground launches of mixed fluid balloons.

- **Solar hot air balloons** have been used for numerous ground-launched missions[7], although it was only recently that JPL discovered that similar balloons could be used at Mars, Jupiter, and Saturn[5]. The true uniqueness of this buoyancy control technique, however, is that where others have failed, JPL has recently found a simple venting mechanism that allows precise altitude control[6]. To date, this buoyancy venting technique has only been confirmed at low altitudes and never for low-pressure (high altitude) deployment and operation, which is the anticipated deployment condition for these planets. The novel vent mechanism would allow balloons to make multiple controlled ground deployments over long distances on Mars, such as deploying four seismic nets (2 kg each) with only an 8 kg balloon. It also allows very long-life balloons on Jupiter and Saturn that can dip into the lower water/ ammonia clouds and survive the nights (~5 hours) by climbing very high before sunset. When a zero pressure helium balloon (lift during day) is combined with a vented infrared Montgolfiere (extra lift at night), long-life altitude control of *thin* terrestrial balloons may be possible without superpressure[8].
- **The use of light stratospheric gas to provide buoyancy at lower altitudes** was only quite recently discovered to be viable at Uranus and Neptune[9]. The extreme distance of these planets from the sun precludes the use of solar-heated balloons, and their primarily hydrogen atmospheres preclude the practical use of pure hydrogen from tanks or the use of heavy RTG power heating sources. Also, there appears to be no simple, quick mechanism to separate the hydrogen from helium and other components while the balloon falls. It was only recently discovered by JPL that the upper methane-free atmosphere, above the cold methane clouds, is substantially lighter (~16% by molecular weight) than the atmosphere below the clouds. This unique feature of Uranus and Neptune allows extremely light balloons (~5 kg) to be used to fly heavier payloads (~10 kg) in the lower atmosphere.
- **RTG-controlled balloon buoyancy** was also very recently discovered by JPL to be viable for certain missions with heavy atmospheres, such as Titan[10]. This moon of Saturn has a relatively thick atmosphere, with a surface pressure of about 1.5 bar, and a temperature of about 93K (-180 °C). The surface atmospheric density is, in fact, about four times higher than the atmosphere at Earth's surface, and thus, helium balloons can provide significant buoyancy with very light mass, just as they do on Earth. A recent study at JPL, analyzed seven different buoyancy control techniques to provide controlled landings on Titan, and concluded that the best approach was to use waste heat from the RTG to actively control the temperature of the helium balloon, and thus its buoyancy[10].

THREE YEAR TECHNICAL APPROACH

Over the next three years, a tentative plan to test all these planetary balloon buoyancy techniques is as follows:

Year 1 – Test Ambient Gas Balloons for Mars/Jupiter/Saturn/Uranus/Neptune

Clearly, the greatest payoff of all these balloon buoyancy techniques is in the ability to use ambient gas from a planet's own atmosphere to provide buoyancy, instead of bringing along a supply of high pressure gas canisters. The solar Montgolfieres proposed for Mars, Jupiter, and Saturn, as well as the stratospheric light gas balloons for Uranus and Neptune, do indeed, use only ambient gas to provide buoyancy. The stratospheric deployment testing of *non-altitude-controlled* solar Montgolfieres is presently in progress at JPL, and two successful stratospheric deployments have already occurred, with three more planned for later in 1999[6]. Furthermore, one *low altitude de*ployment of an altitude-controlled Montgolfiere has also occurred, but there have been no tests to confirm high altitude deployment of vented Montgolfieres. This type of deployment is significantly more difficult than that for a sealed Montgolfiere, in that the lightweight, vent mechanism must survive intact during deployment falling speeds as high as 50 m/sec. Thus, a series of high altitude deployment tests is planned for Montgolfieres with upper vents attached. On Mars, deployment must occur at about 0.003 bar, while on Jupiter and Saturn, deployment can occur at about 0.1 bar. Also, some initial low altitude drop tests will occur for the similar Uranus/Neptune ambient gas balloons, which will *trap* ambient gas, with high altitude tests to proceed during the second year. Finally, a complete analysis will be conducted as to how to best control altitudes of stratospheric terrestrial balloons. A promising method is to combine infrared Montgolfieres (trap Earth's radiant heat at night) with zero pressure helium balloons[8]. Other methods are sorption of gases, and variable emissivity balloons.

Year 2 – Further Tests of Ambient Gas Trapping Balloons as well as Heated Helium Techniques
During the second year, designs will be finalized for high altitude tests of Uranus/Neptune ambient gas balloons, as a result of low altitude drop tests in the first year. These balloons will be dropped from 0.1 bar altitude (16 km), and will be sealed after filling. The balloons will be collected on the ground and checked for leakage at the sealing mechanism. Tests on the RTG-heated helium buoyancy technique for Titan balloons will be conducted in the high clearance balloon room at JPL's Planetary Balloon Laboratory. A heating mechanism will be designed that has similar power (<1000 watts) and temperatures (<300°C) to the RTG power source intended to be used for Titan missions. A radiant door mechanism will be remotely operated, and the balloon's lift and temperature will be monitored as a function of time. All results will be compared with theory, and a Titan balloon model will be updated. Tests will also be started on preferred terrestrial balloon altitude techniques, with launches supplied through the NASA Balloon Program.

Year 3 – Final Terrestrial Balloon Tests and Venus Mixed Gas Phase Change Altitude Control Tests
In the third year, larger altitude-control terrestrial balloon tests will be performed with payloads up to about 100 kg at 0.01 bar altitude (29 km), and the balloons will be actively controlled to land at pre-designated sites, with launches supplied through the NASA Balloon Program.[11] In addition, a low altitude Venus-simulation test will be conducted using 10% methanol (or equivalent) evaporated in a balloon partially filled with helium. The amount of methanol will be varied, and the condensation height compared parametrically with analysis. This test will confirm the ability to have viable repeated controlled landings of Venus balloons, while reaching higher cold altitudes.

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